Automated Geospatial Watershed Assessment (AGWA) Tool:

Introduction, background, and applications

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April 19, 2015
SedHyd

Overview

- AGWA Background & Basics

- Watershed Assessments with AGWA

- AGWA use by BAER Teams

- Modeling Expectations

- Rainfall Representation Impacts

- Lessons Learned

Major Groups Involved in AGWA Development

USDA-ARS   US-EPA   USGS
University of Arizona   University of Wyoming

AGWA – Background - Basics

- **An <u>automated GIS interface</u> for watershed modeling (hydrology, erosion, WQ) designed for resource managers**

- **Applicable to ungauged / gauged watersheds**

- **Operates with nationally available data (DEM, Soils, Land Cover)**

- **Investigate the impacts of land cover change**
  - **Historical and future**
  - **Identify sensitive, "at-risk" areas**
  - **Assess impacts of management (e.g. growth, fire, mulch)**

- **Provide repeatable results for <u>relative change assessments</u>**

- **Must have good rainfall-runoff observations for quantitative predictions**

- **Three established watershed/hillslope models for multiple scales**
  - **SWAT**
  - **KINEROS2**
  - **RHEM/WEPP (hillslope runoff and erosion)**

- **Over 4,000 registered users in 159 countries**

SWAT | Soil & Water Assessment Tool


KINEROS2 — A KINEMATIC RUNOFF AND EROSION MODEL

AGWA – *Watershed Models*

- **Two distributed hydrologic models to address multiple scales**
  - ***SWAT* for large basins, daily time steps (HRU – Hydrologic Response Units, CN-Curve Numbers)**
  - ***KINEROS2* small/med. basins, sub-hour time steps, dynamic routing and physically-based infiltration, runoff-runon, cascade of elements, allows explicit treatment of different cover and management**
- **Endpoints: runoff, erosion, sediment, plus N and P in SWAT**

SWAT Abstract Routing Representation

channel 73

pseudo-Ch. 71
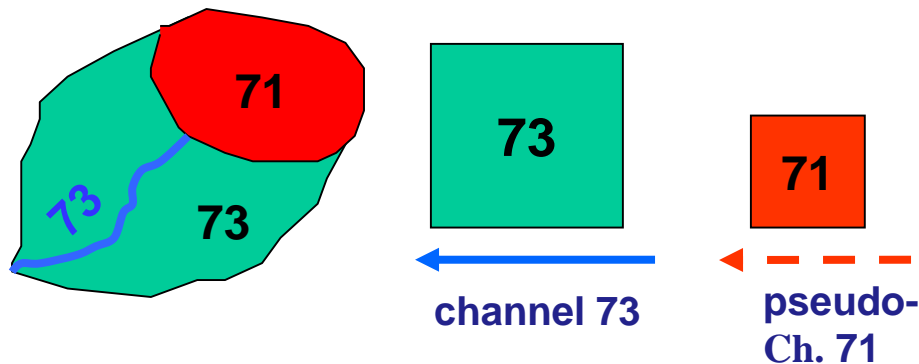
KINEROS2 Abstract Routing Representation
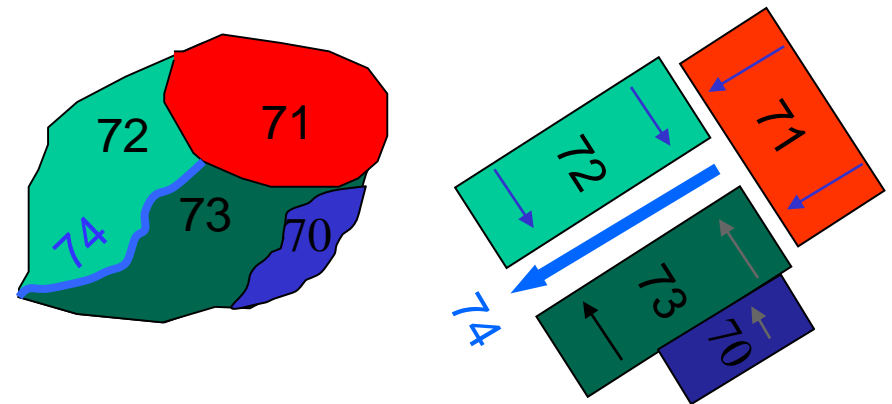
Conceptual Design of AGWA

PROCESS

Build GIS Database

↓

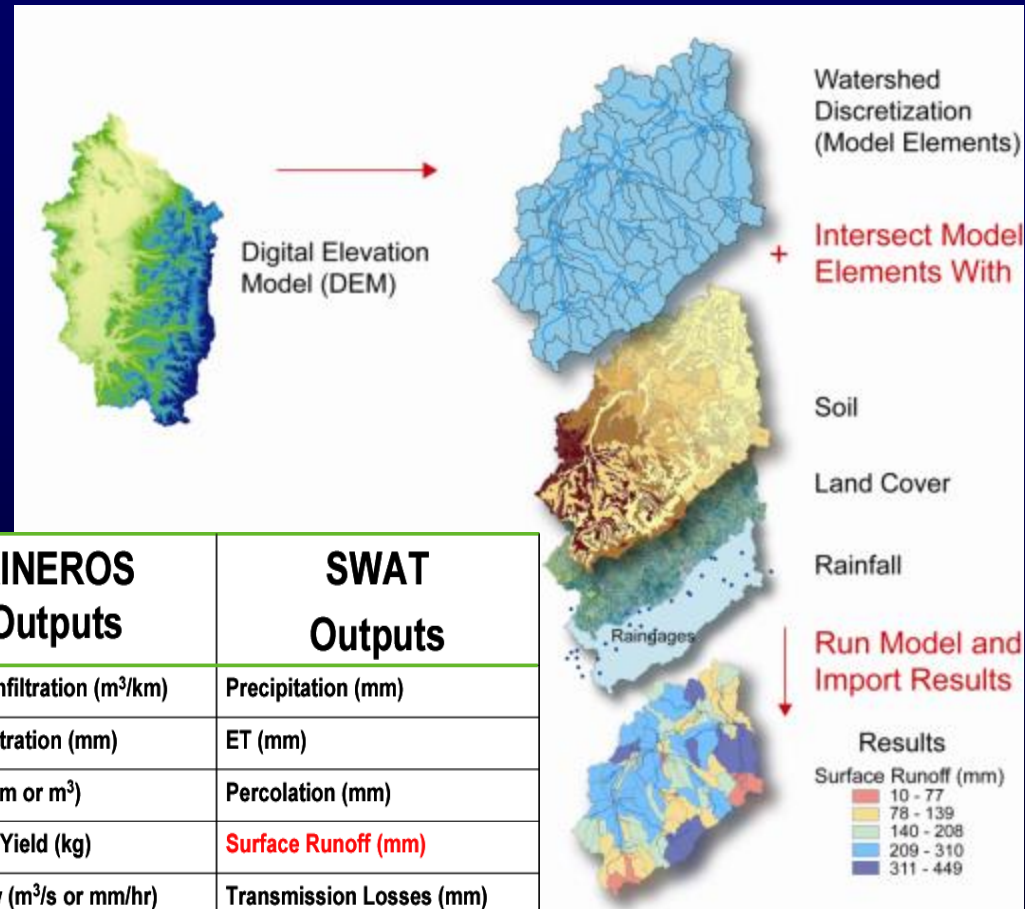Discretize Watershed
f (topography)

↓

Characterize Model Elements
f (land cover, topography, soils)

↓

Derive Secondary Parameters
look-up tables from Exp./Res.

↓

Build Input Files
& Run Model

↓

View Model Results
link model to GIS

INPUTS & OUTPUTS

Digital Elevation Model (DEM) → Watershed Discretization (Model Elements)

+ Intersect Model Elements With

Soil

Land Cover

Rainfall

Raingages

Run Model and Import Results

Results
Surface Runoff (mm)
- 10 - 77
- 78 - 139
- 140 - 208
- 209 - 310
- 311 - 449

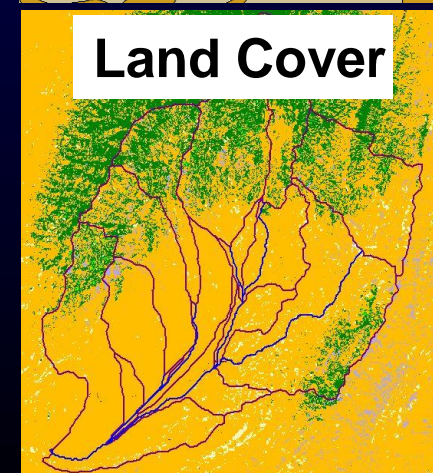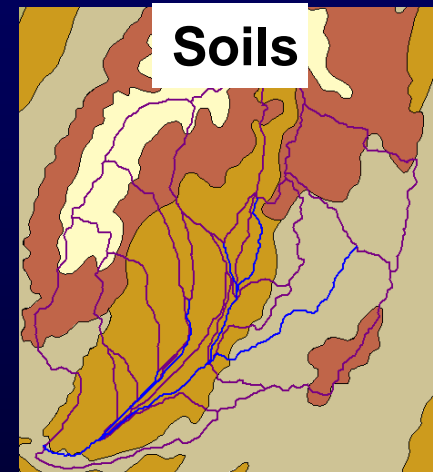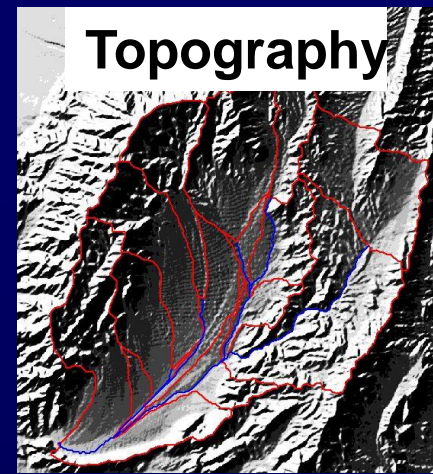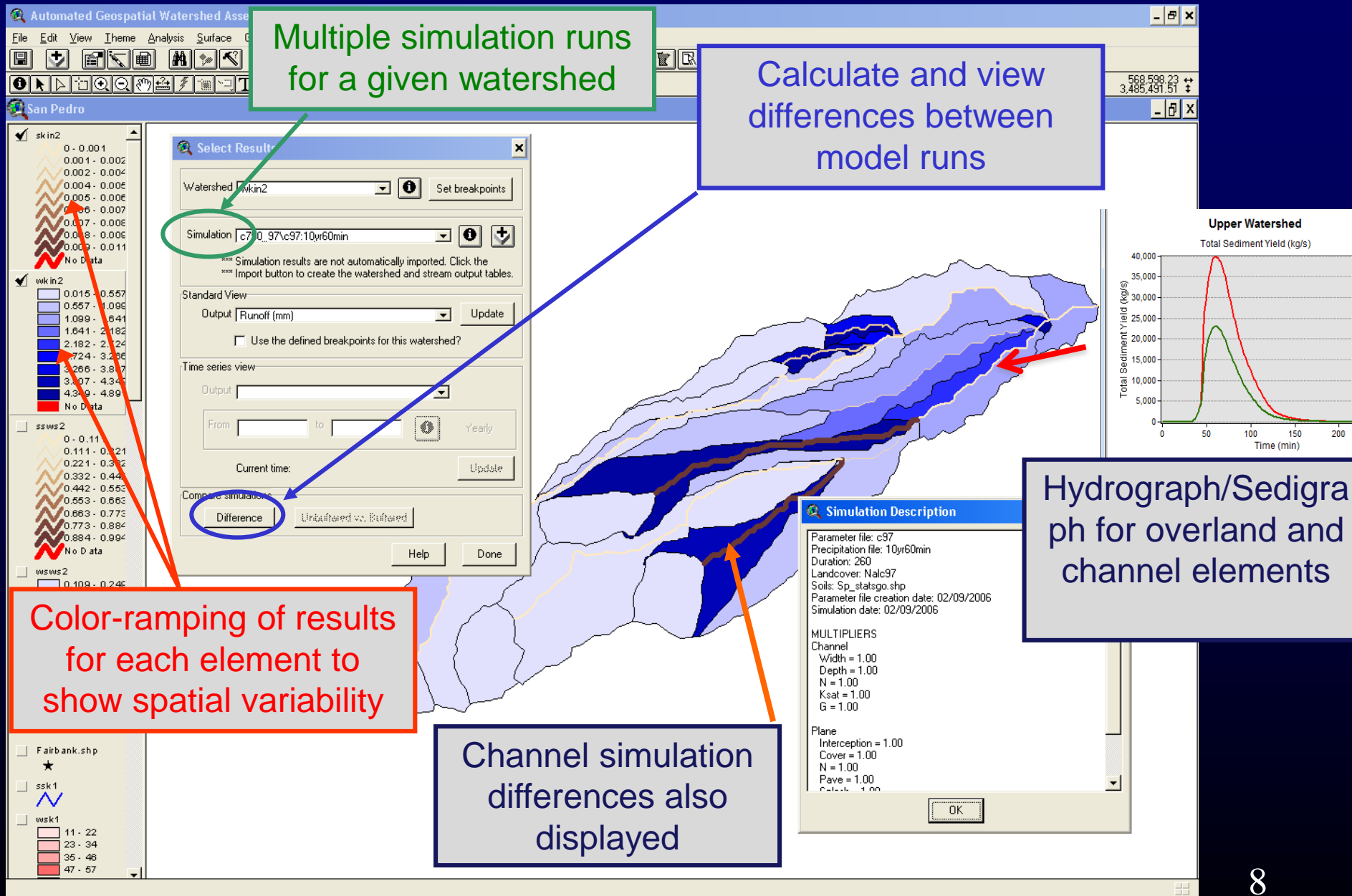| KINEROS Outputs	SWAT Outputs
Channel Infiltration (m^3/km)	Precipitation (mm)
Plane Infiltration (mm)	ET (mm)
Runoff (mm or m^3)	Percolation (mm)
Sediment Yield (kg)	Surface Runoff (mm)
Peak Flow (m^3/s or mm/hr)	Transmission Losses (mm)
Channel Scour (mm)	Water Yield (mm)
Sediment Discharge (kg/s)	Sediment Yield (t/ha)
	Nitrate in Surface Runoff (kg N/ha)
	Phosphorous in Surface Runoff (kg P/ha)

Data for AGWA Parameterization

Topography

- **Digital Elevation Model**
  - **Usually USGS 10m – 30m DEM will work fine in western terrains in large watersheds**
  - **LIDAR can be used**
- **Soils**
  - **USDA STATSGO – nationally available; SSURGO where available**
  - **FAO soils globally**

Soils

- **Land Use - Land Cover (NLCD, ReGAP)**
- **Weather**
  - **If not using design storms - "good" rainfall data is essential in time/space (more later)**
- **Management Information**
  - **Where and What**
  - **Information must be provided by user! (i.e. burn severity map)**

(Examples and more detail in the 1st training tutorial)

Land Cover

Visualization of Results

Multiple simulation runs for a given watershed

Calculate and view differences between model runs

Color-ramping of results for each element to show spatial variability

Hydrograph/Sedigraph for overland and channel elements

Channel simulation differences also displayed

How AGWA tools Fits into Comprehensive Watershed Assessments and Analysis

Impact of Historical Landscape Change (e.g. San Pedro/New York City)

Alternative Futures (e.g. San Pedro, Willamette River, South Platte)

AGWA (Runoff, Peak Discharge, Sedimentation, Nitrogen, Phosphorous)
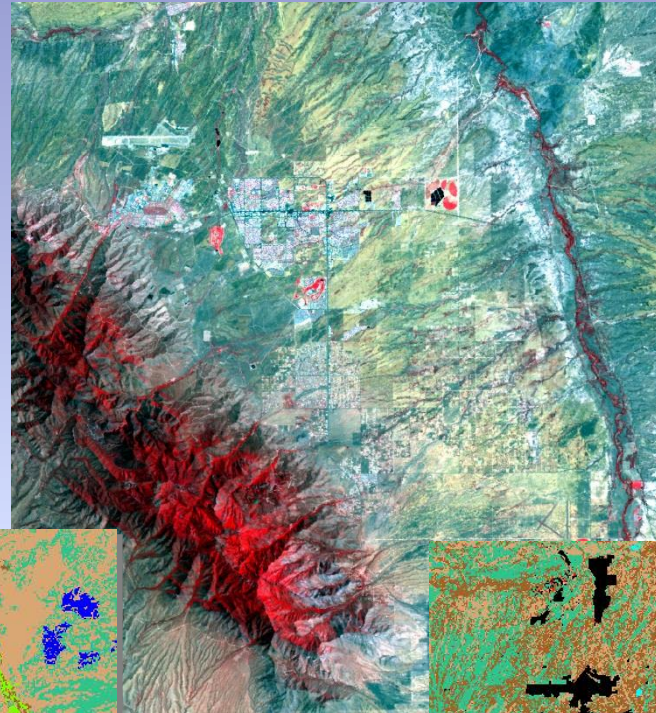
Sub-catchments/Stream Segments at Risk to Increased Sedimentation and Run-off (e.g. 404q, post-fire)

Decision Support Tool for Watershed Assessment and Watershed-based Planning (e.g. GI, BMPs, Border 2020)
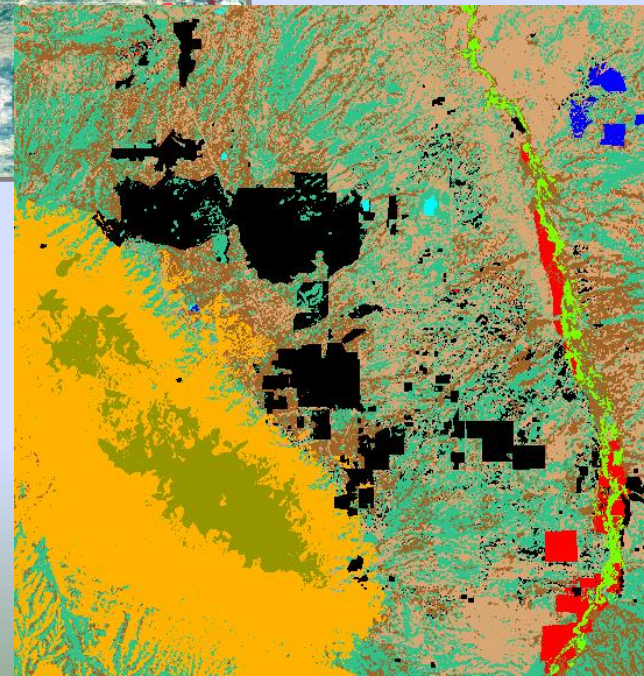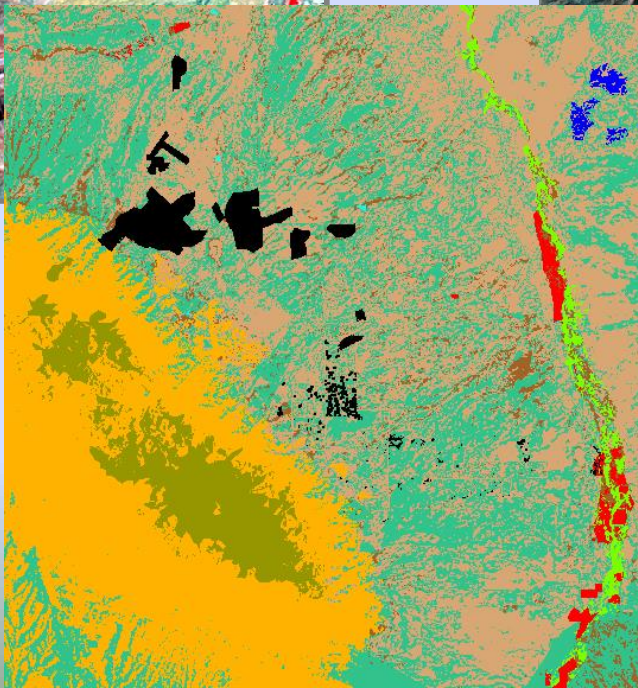
Sierra Vista Arizona: Land Cover / Land Use
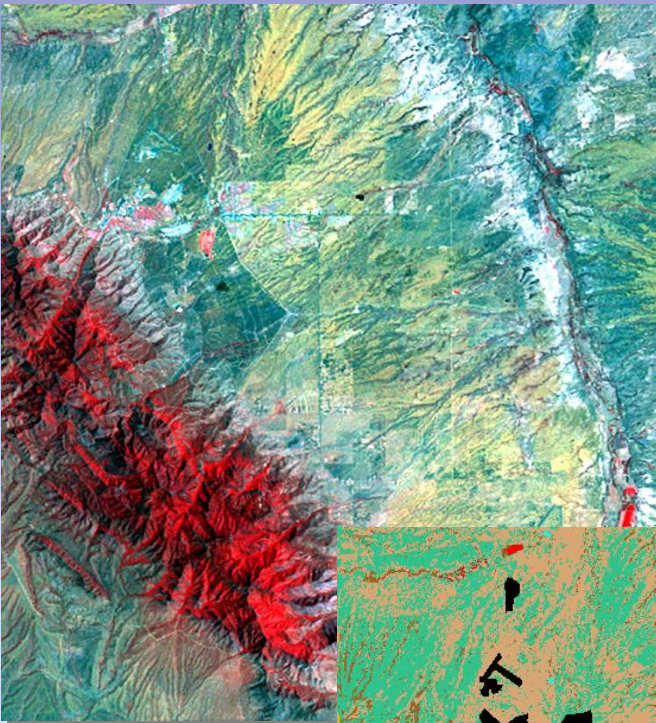
1973

1997

Spatial and Temporal Scaling of Results

- ➢ **Using SWAT and KINEROS for integrated watershed assessment**
- ➢ **Land cover change analysis and impact on hydrologic response**

Upper San Pedro River Basin

High urban growth 1973-1997

ARIZONA

Phoenix

Tucson

SONORA

N

Water Yield change between 1973 and 1997

<<WY   >>WY

SWAT Results

Sierra Vista Subwatershed

KINEROS Results

Concentrated urbanization

1997 Land Cover

- Forest
- Oak Woodland
- Mesquite
- Desertscrub
- Grassland
- Urban
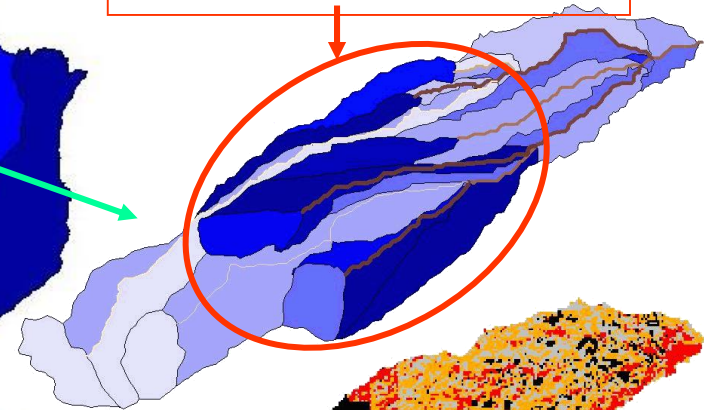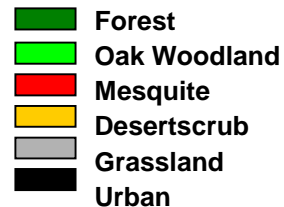
Rapid Post-Fire Watershed Assessment using AGWA

- 2011 – Wallow Fire, AZ
  - The only model that produced results for the entire burned area
- 2012 – Las Conchas, NM; Trinity Ridge, ID; L. Bear, NM
- 2013-14 – Mountain, CA; Elk & Pony Complex, ID; Mile Marker 28, WA; Rim, CA; Silver, CA 2014 - ?? Ask Scott
- Typical BAER Team Use of AGWA
  - Pre-deployment gather data & develop pre-fire model simulations
  - Whenever possible, use burned area reflectance classification (BARC) map for initial AGWA simulations to stratify field work
  - Use field verified burn severity map (BSM) for post-fire simulations and difference them with pre-fire simulations
  - BAER specialists use AGWA results and field observations to design response actions & recommendations to local emergency management
  - Depending on the values-at-risk, the BAER team may use AGWA to evaluate "modeled" benefits with the proposed remediation design

Post-Fire Assessments

- **Define look-up table for pre- and post-fire model parameters as a f (land cover & burn severity) from well gaged basins**
  - **SWAT (CN, roughness)**
  - **KINEROS2 (roughness, Interc., cover, Sat. Hydraulic Cond.)**

- **Pre-fire data and simulations can be done for any given watershed at any time or in run up to BAER deployment**

- **Import post-fire burn severity map as a shape file**

- **Run model with same rainfall input as pre-fire simulation**

- **Difference post- and pre-fire simulations and spatially display results**

- **Allows rapid visual recognition of watershed areas most prone to post-fire impacts so mitigation and remediation can be targeted**
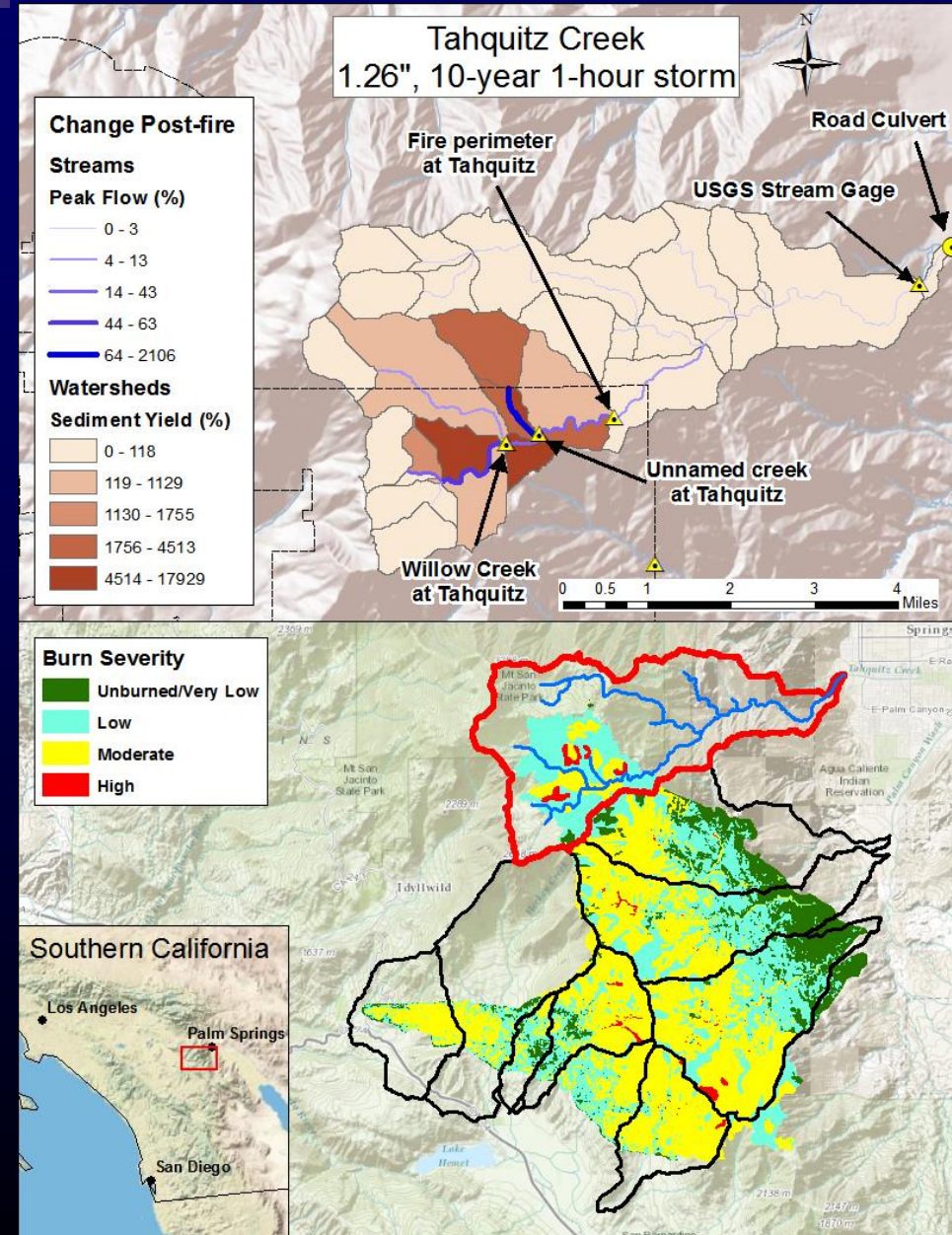
Parameterization for Post-Fire (K2)

- Based on analysis of watersheds with good pre- and post-fire rainfall and runoff data

- Assume a reduction in cover of:

  15% - low severity

  32% - moderate severity

  50% - high severity

  (In K2 a cover reduction also decreases infiltration rates)

- Fix the roughness factor for overland flow to equal bare soil (n = 0.011). Selection of this value allows for more than an order of magnitude change in extremely rough environments, such as conifer forests.

Aug. 12, 2013

- **I.D. Points of Interest (POI) & Values at Risk (VAR)**

- **Discretize watersheds to these points**

- **Simulate pre-fire conditions with SCS Type II spatially uniform storm**

- **Import burn severity map**

- **Simulate post-fire (same storm)**

- **Difference pre- and post-fire simulations**

- **Results served BAER purposes**

Tahquitz Creek
1.26", 10-year 1-hour storm

Change Post-fire
Streams
Peak Flow (%)
- 0 - 3
- 4 - 13
- 14 - 43
- 44 - 63
- 64 - 2106

Watersheds
Sediment Yield (%)
- 0 - 118
- 119 - 1129
- 1130 - 1755
- 1756 - 4513
- 4514 - 17929

Fire perimeter at Tahquitz
Road Culvert
USGS Stream Gage
Unnamed creek at Tahquitz
Willow Creek at Tahquitz

Burn Severity
- Unburned/Very Low
- Low
- Moderate
- High

Southern California
Los Angeles
Palm Springs
San Diego

KINEROS2 Modeling Expectations

- **Recent study compares pre- and post-fire modeling results for Rule of Thumb (ROT), Modified Rational Method (MODRAT), HEC-HMS Curve Number, and KINEROS2 in San Dimas Exp. Forest (Chen et al 2013)**

    - **ROT & MODRAT – OK with careful local calibration**

    - **HEC-HMS CN better for pre-fire prediction**

    - **KINEROS2 better for post-fire prediction**

    - **Evidence that pre-fire runoff is Sat. Excess or Subsurface and post-fire is Inf. Excess**

    - **KINEROS2 (as currently setup in AGWA) only does Inf. Excess (can do Sat. Excess from shallow soils over rock) – tutorials will get into more complex model setups**
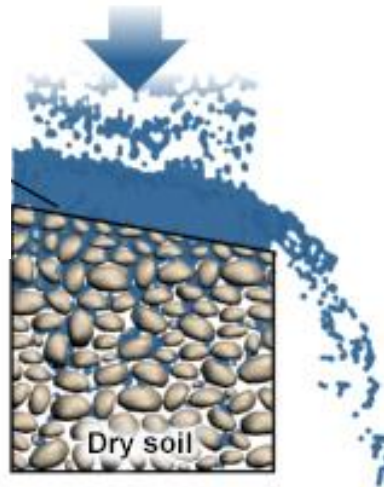
Basics of Runoff Generation

Interflow – Shallow Subsurface Flow

Infiltration Excess

Saturation Excess

Bedrock

Dry soil

Saturated soil
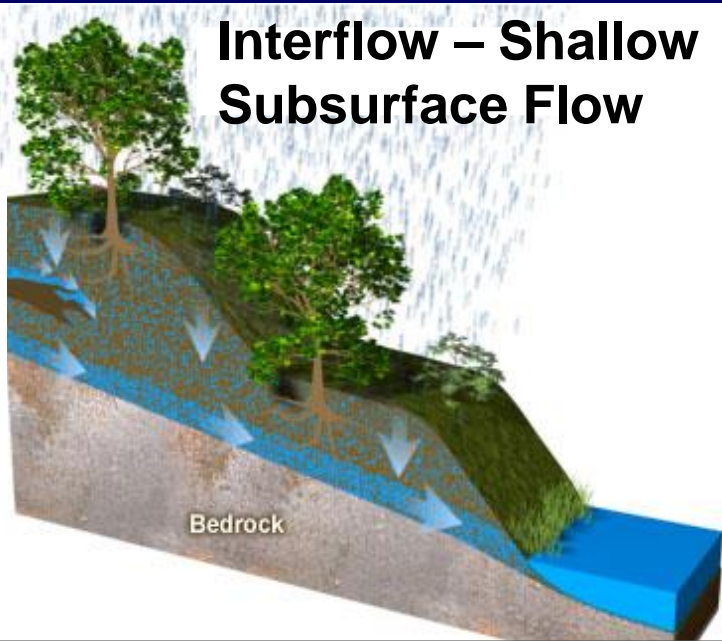
Infiltrated rain hits restrictive layer and flows laterally to stream (slow response, attenuated peak)

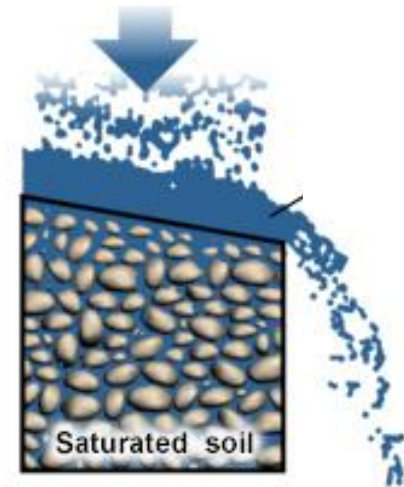**Typical in unburned areas with shallow soils and heavy litter**

Rainfall Int. > Soil Infil. Rate

Typical in burned areas – high Int. rain

Soil pores saturated

Wet areas – shallow water table or shallow soil over rock

KINEROS2 – as set up in AGWA

CN better represents this mechanism

Marshall Gulch

Pre - Fire Hydrograph
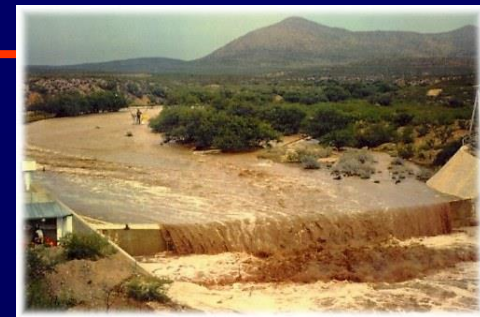
8/16/57 – 8/26/57
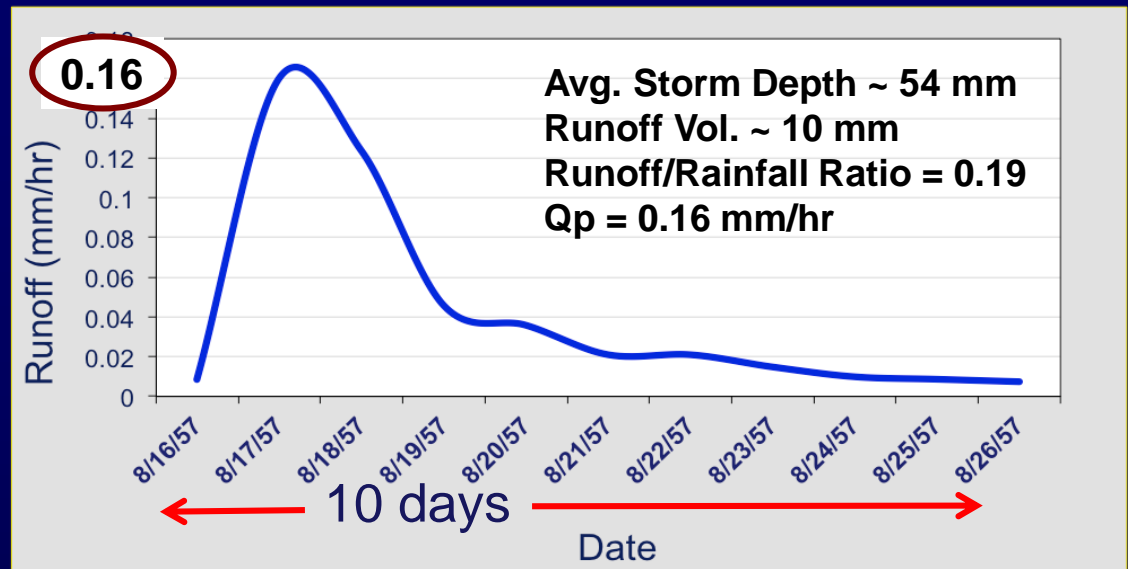
Post - Fire Hydrograph

7/24/03

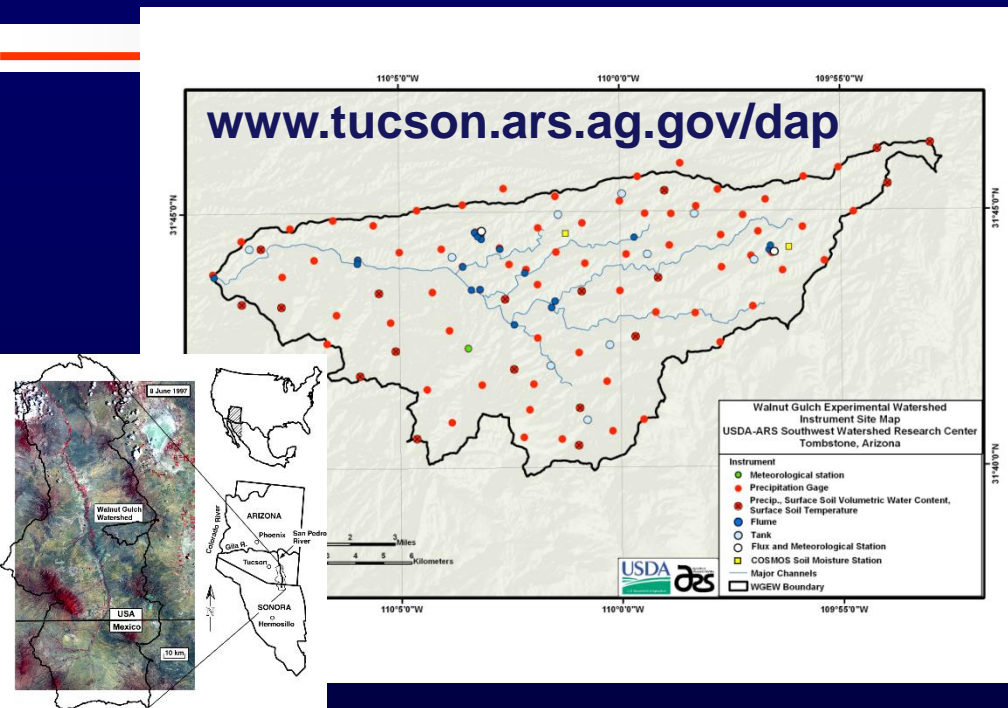*(Aspen Fire – 6/17/03 ~ 7/10/03)*

Avg. Storm Depth ~ 54 mm
Runoff Vol. ~ 10 mm
Runoff/Rainfall Ratio = 0.19
Qp = 0.16 mm/hr

0.16

10 days

Runoff (mm/hr)

Date

Avg. Storm Depth ~ 43.9 mm
Runoff Vol. ~ 4.7mm
Runoff/Rainfall Ratio = 0.11
Qp = 41.4 mm/hr

3 hours

40

Runoff (mm/hr)

Time (minutes)
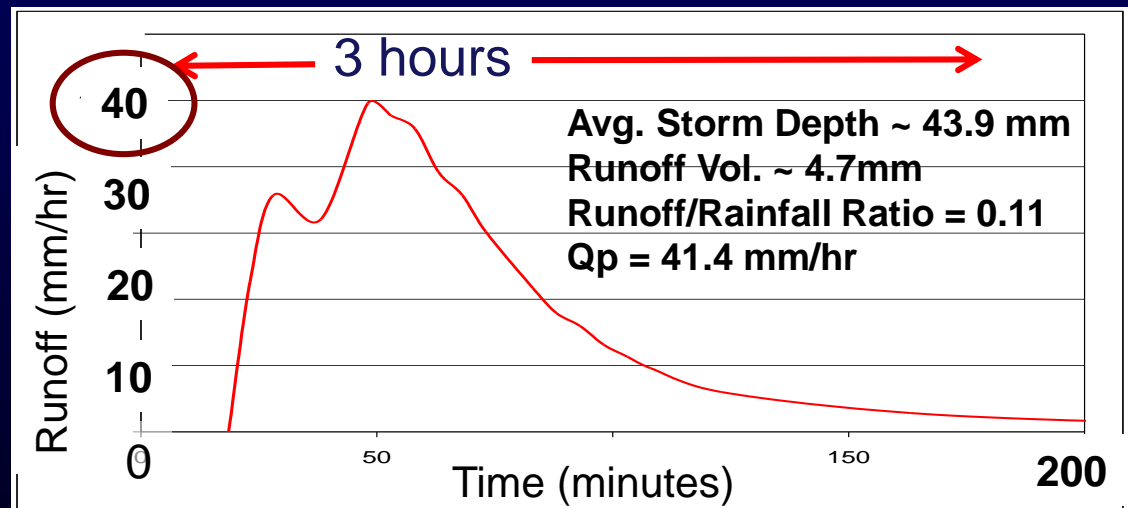
Runoff / rainfall ratio similar; timing & peak runoff rate are profoundly different (also noted by Springer & Hawkins 2005; McLin et al. 2001).

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USDA-ARS Walnut Gulch Experimental Watershed

www.tucson.ars.ag.gov/dap

Walnut Gulch Experimental Watershed
Instrument Site Map
USDA-ARS Southwest Watershed Research Center
Tombstone, Arizona

Instrument
- ● Meteorological station
- ● Precipitation Gage
- ● Precip., Surface Soil Volumetric Water Content, Surface Soil Temperature
- ● Flume
- ○ Tank
- ○ Flux and Meteorological Station
- ▣ COSMOS Soil Moisture Station
- — Major Channels
- ▭ WGEW Boundary

- **Drainage Area: 149 km^2**
- **Ave. annual Precipitation: 312 mm**
    - **60% from N. American Monsoon**
    - **35% frontal winter**
    - **~5% from tropical depressions**
- **54 years record**
- **88 weighing recording rain gauges, 1 min.**
- **29 gaged watersheds (8 with sediment)**

Model Limitations – Poor Predictions for Small Runoff Events

Walnut Gulch (148 km²) Average Annual Water Balance

PPT 350 mm

- Small errors and uncertainties in rainfall Obs. can result in large uncertainties in runoff
  - Typical rain gauge measurement error ~ 3mm
  - Wind induced gauge errors ~ 5 to 15% of total

Model Limitation

In arid in semiarid regions where runoff / rainfall ratios are small, we are between a rock and hard place.

We can't expect any watershed model to make good predictions for small runoff events – especially without very good rainfall observations

mm

20 mm

Runoff 2 mm

High & Low Runoff to Rainfall Ratio

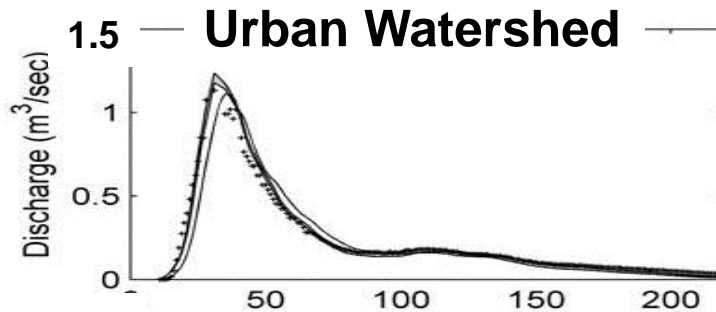**~27 fold increase in runoff due to urbanization**
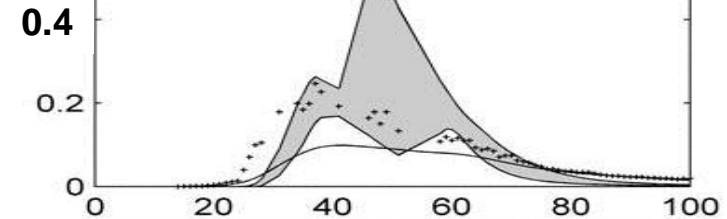
4 Gages

Ft. Huachuca (grasslandl)

La Terreza (urban)
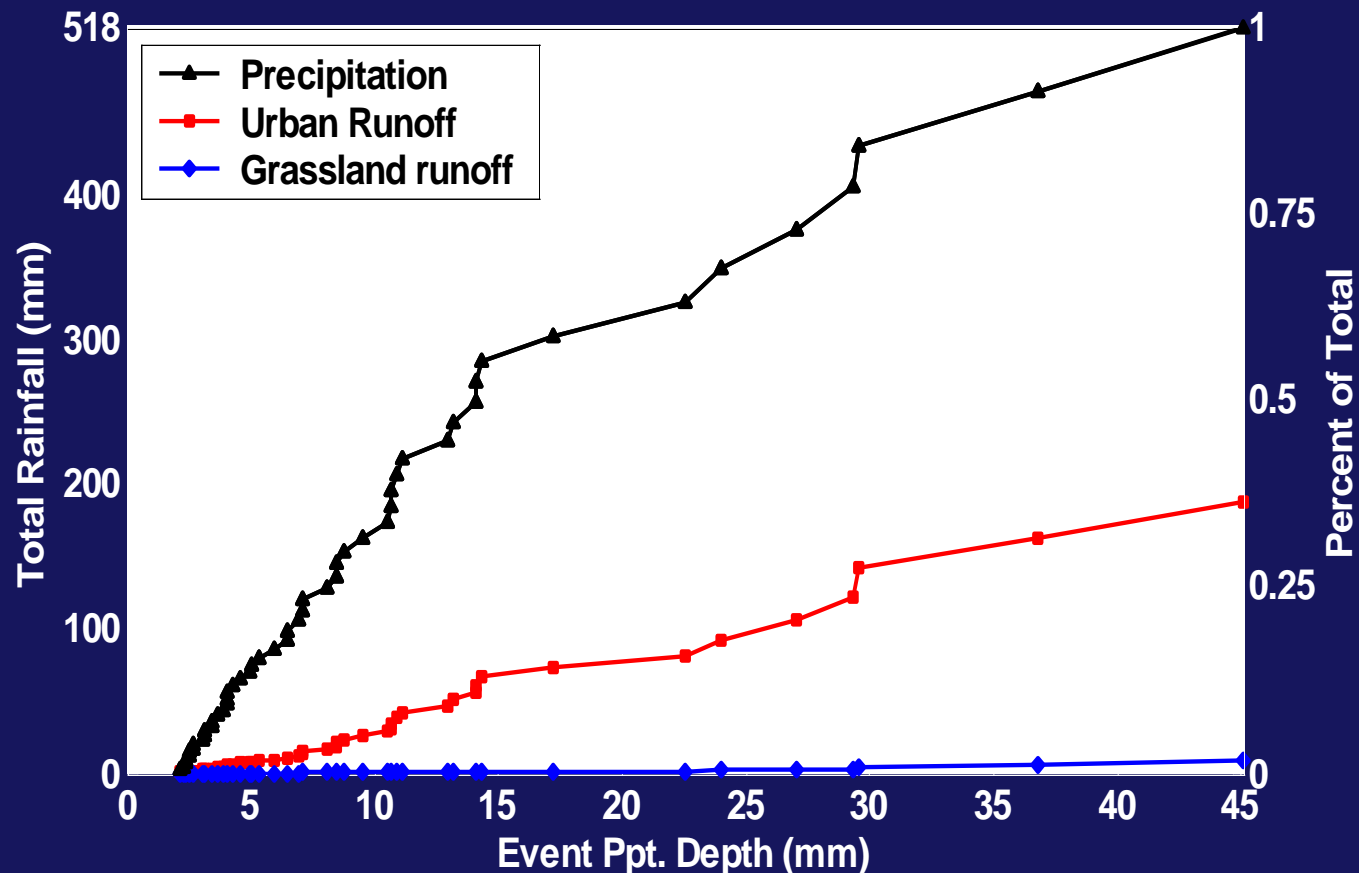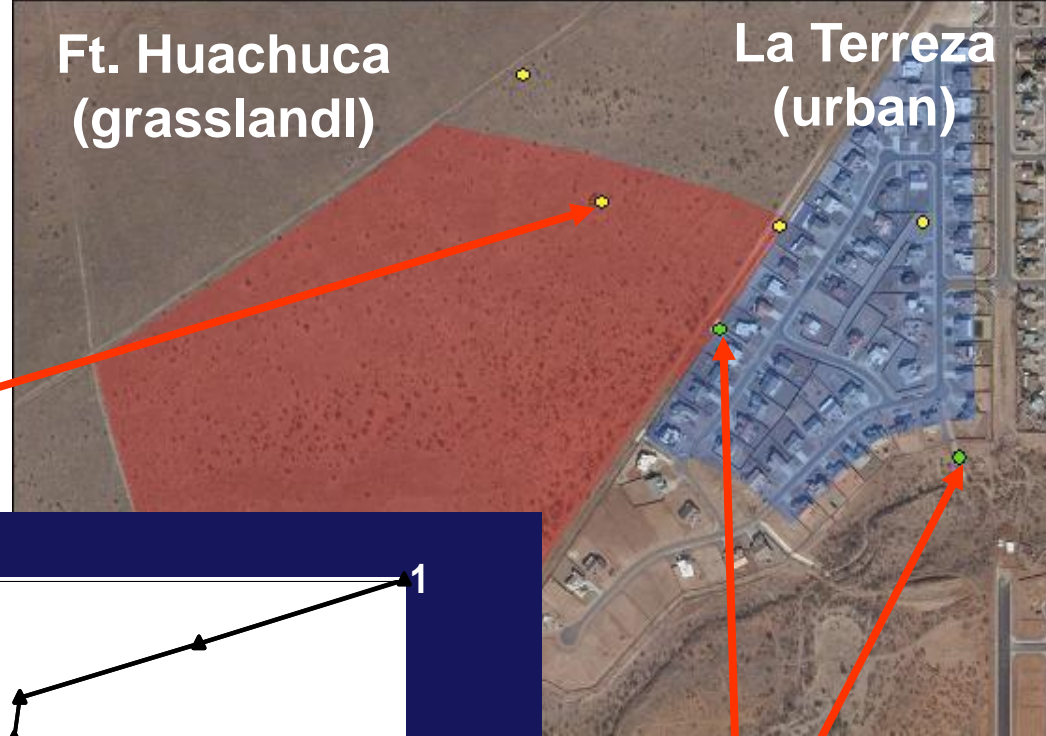
Runoff

Low Runoff-Rainfall Ratio => High Model Prediction Uncertainty
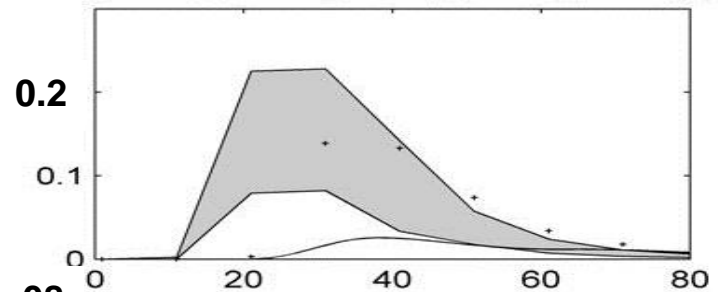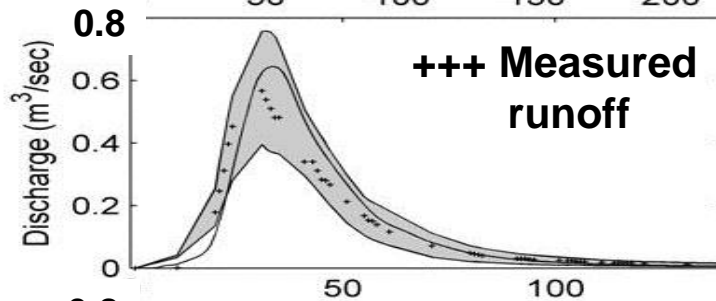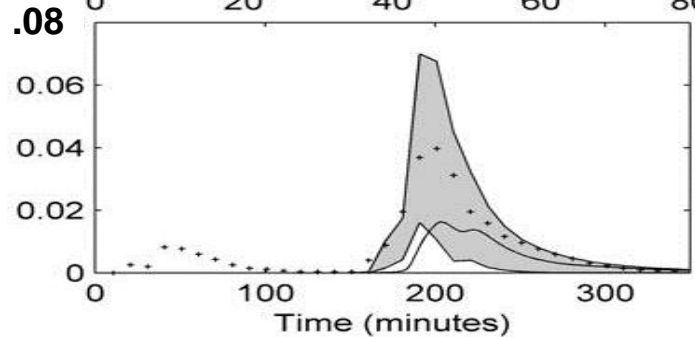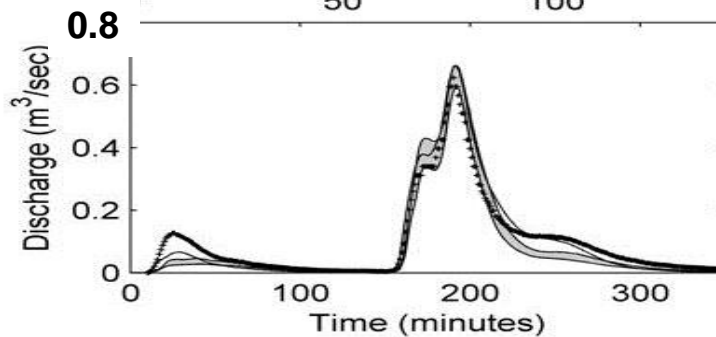

Bands indicate level of modeling uncertainty (shaded)
Simulated runoff using calibrated parameters (solid line)
Point: Any **model will make poor predictions when runoff is a small % of rainfall**
**due to uncertainties in rainfall and other model parameters**   *Kennedy et al. 2013*

SCS 24-hour Rainfall Distributions with NOAA Design Storm Depths

Type I and IA – Pacific maritime climate with wet winters and dry summers. Long duration, low intensity events.

Type III – Gulf of Mexico and Atlantic coastal areas where tropical storms bring large 24-hour rainfall amounts

Type II – Everywhere else, intense short duration rainfall, smaller extents.
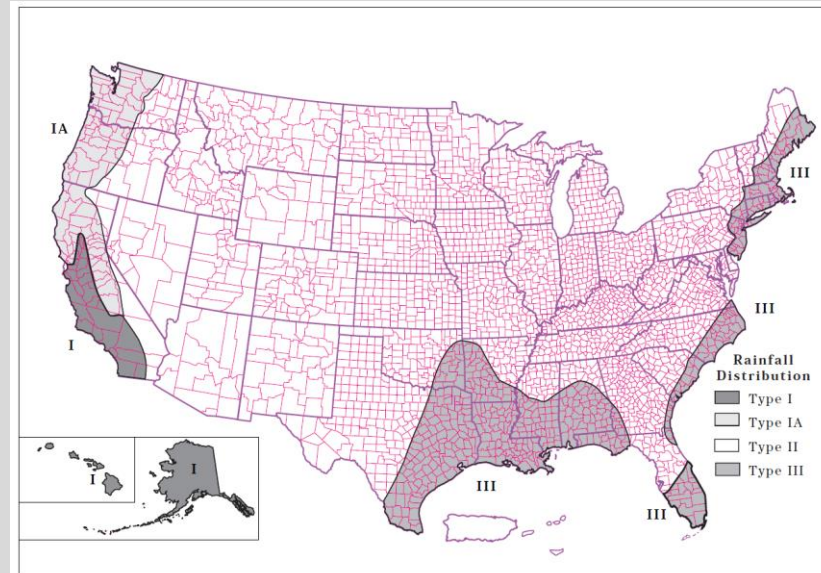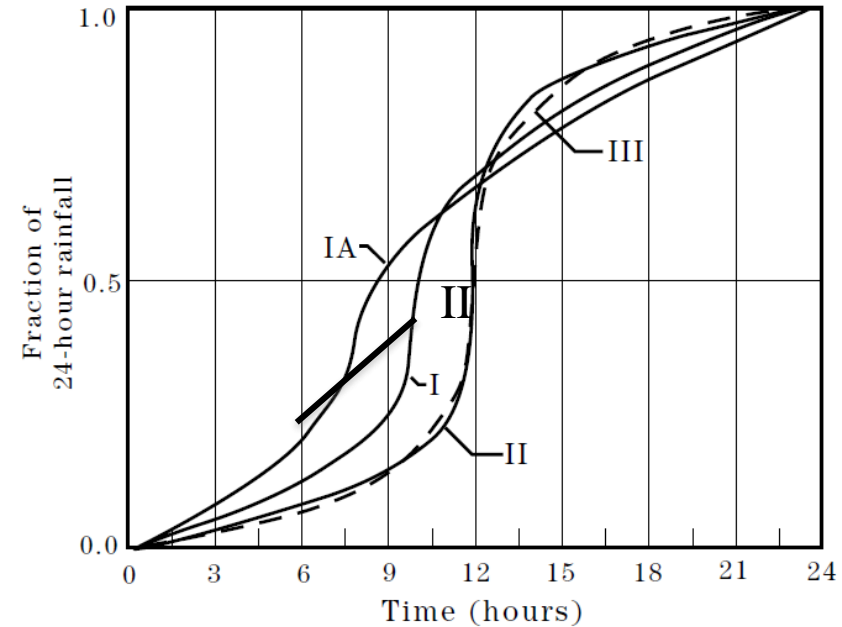
How should rainfall be input into the model?

Typical goals when modeling post-fire runoff

1) Accurately predict or reproduce magnitude of an event

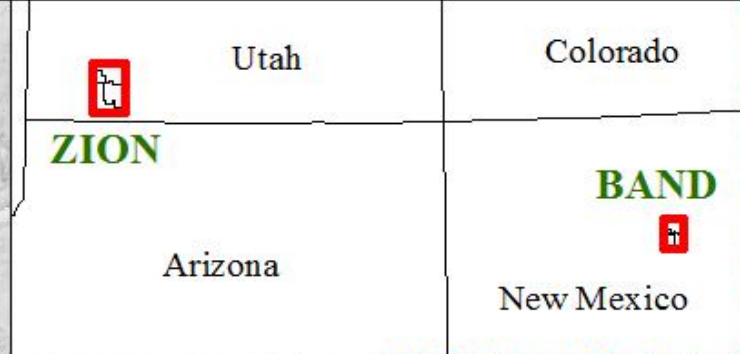2) Predict which stream reaches and hillslopes are at risk (values at-risk)

How does rainfall representation affect our ability to meet these goals?

Zion National Park — North Creek

August 1, 2007 storm
>1 year after the fire

Utah Colorado
ZION
Arizona BAND
New Mexico

Bandelier National Monument — Frijoles Canyon

August 21, 2011 storm

Park Boundary
Watershed
Stream
Stream Gage

Burn Severity
Unburned
Low
Moderate
High

N

0 2.5 5 10
Kilometers

0 2.5 5 10
Kilometers
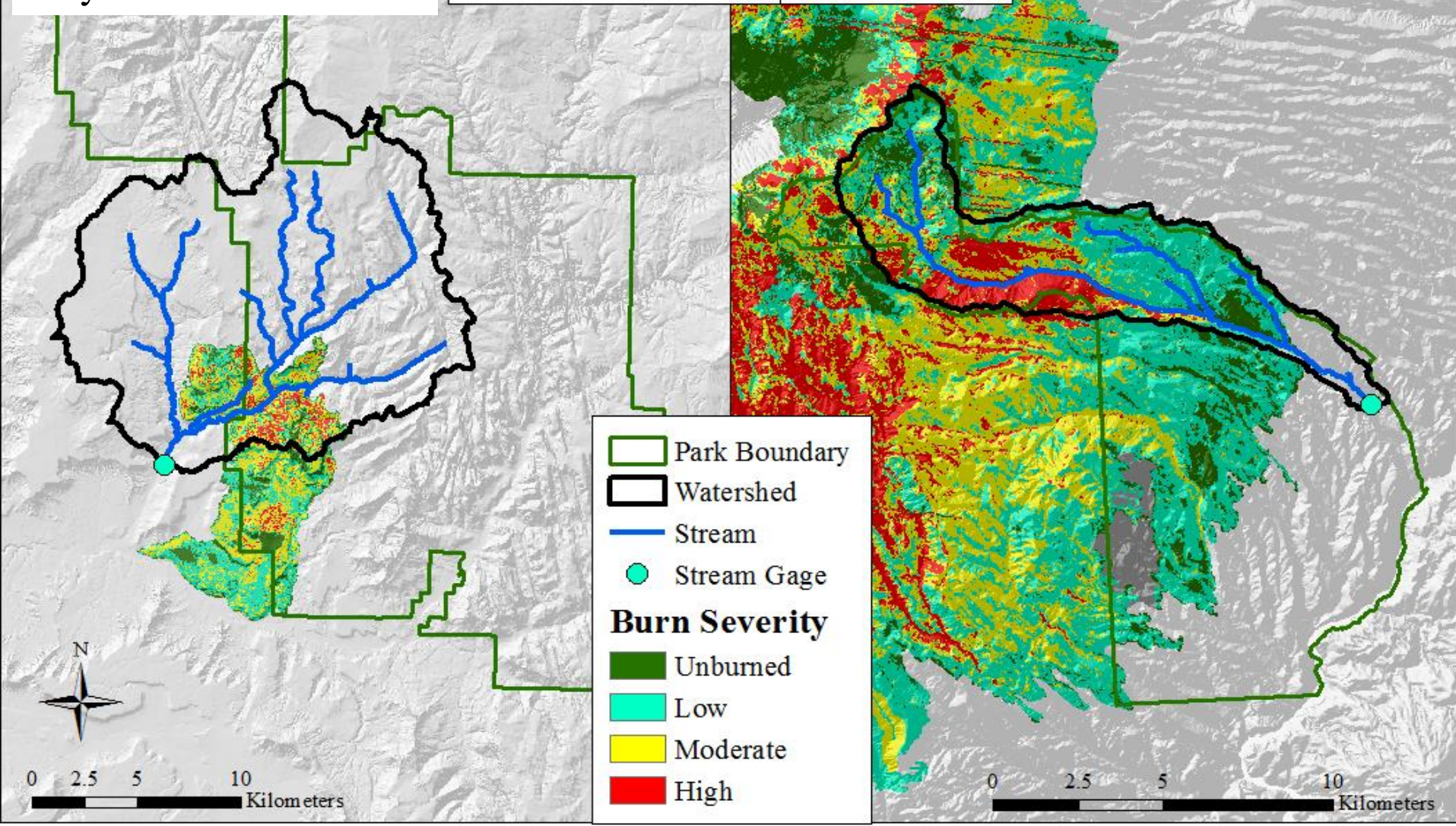
Reproducing Post-fire Flood Magnitude

What rainfall representation gives us the best estimate of peak discharge?
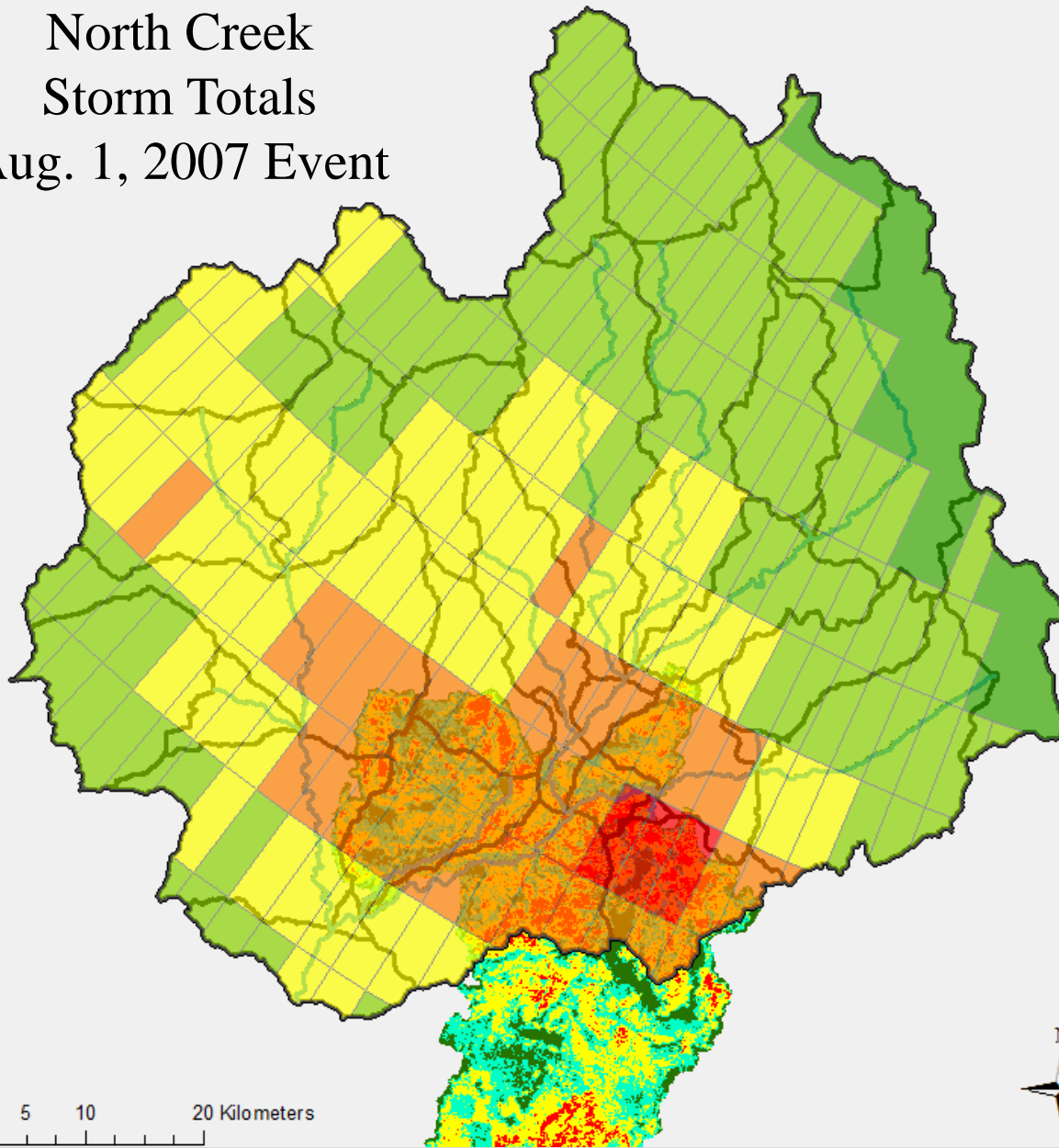
Rainfall representations input into the model:
1. <u>Uniform</u> rainfall intensity over the entire watershed
2. <u>SCS Type II</u> storm over the entire watershed
3. <u>SCS Type II</u> storm centered over <u>the burned area</u>
4. Observed Digital Hybrid Reflectivity (DHR) <u>radar</u> data from post-fire event
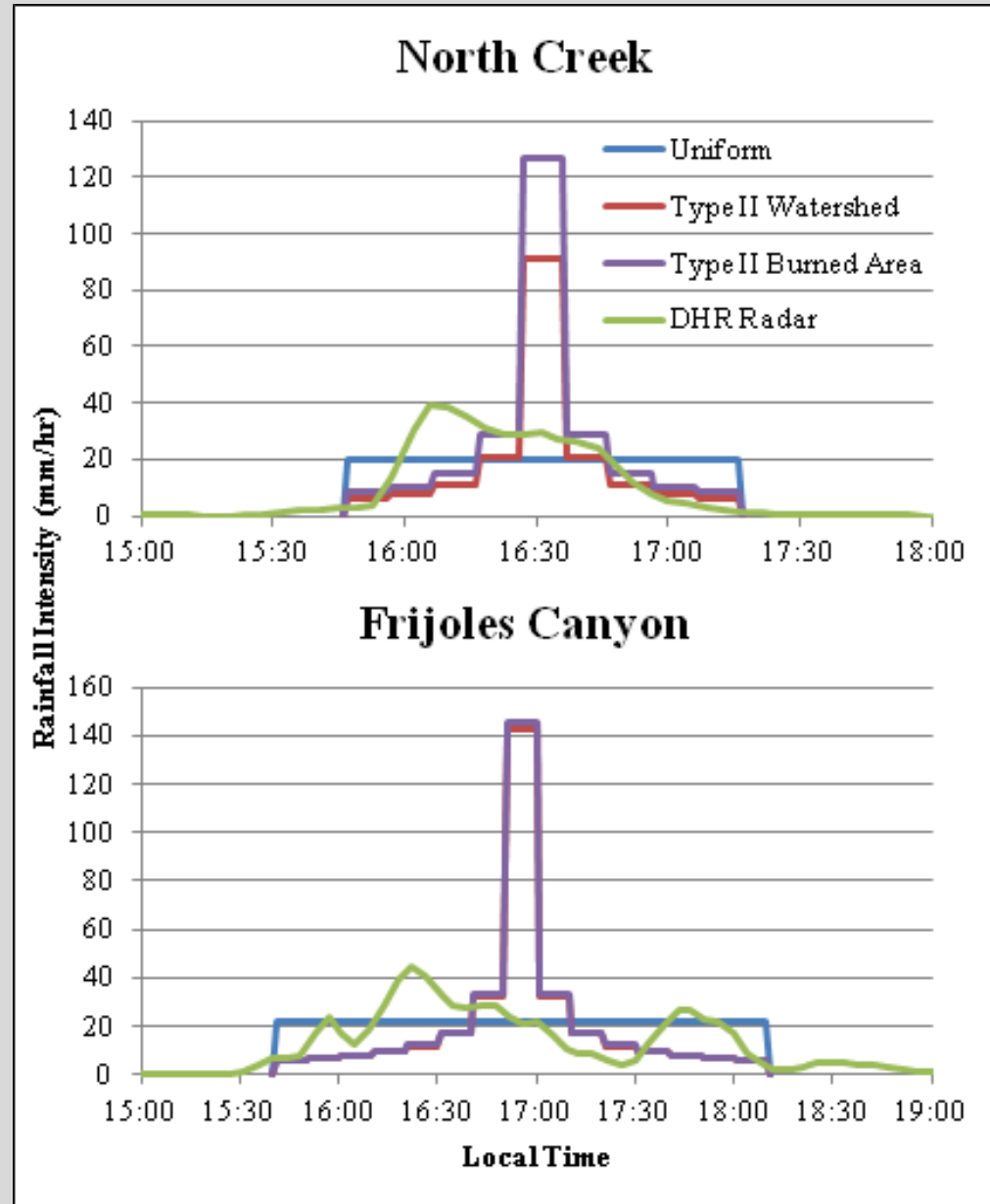
Radar Representation in KINEROS2
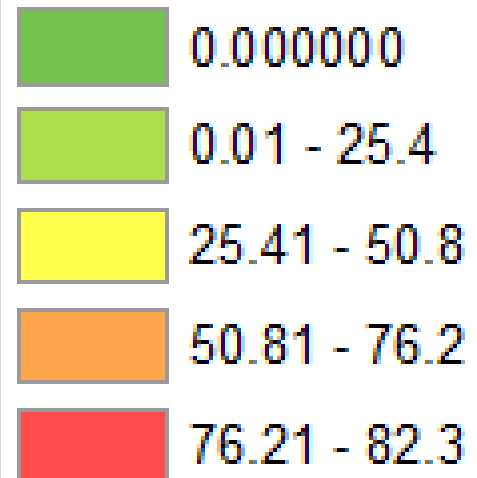
North Creek
Storm Totals
Aug. 1, 2007 Event

• Average rainfall depth over watershed: 30.22mm (1.19")
• Approximate duration of event: 1.5 hours
• Correlates to ~10-year rainfall event

Storm Totals

Rainfall Depth (mm)

🟩	0.000000
🟢	0.01 - 25.4
🟨	25.41 - 50.8
🟧	50.81 - 76.2
🟥	76.21 - 82.3

0   5   10   20 Kilometers

N

Post-fire Magnitude: Results

Rainfall Representation	Peak Discharge (m3/s)	Time to Peak (min)
Uniform	2.53	355
Type II	64.69	215
Type II Burned Area	261.23	189
DHR Radar	312.91	184
USGS Estimate	382.33	~180-240
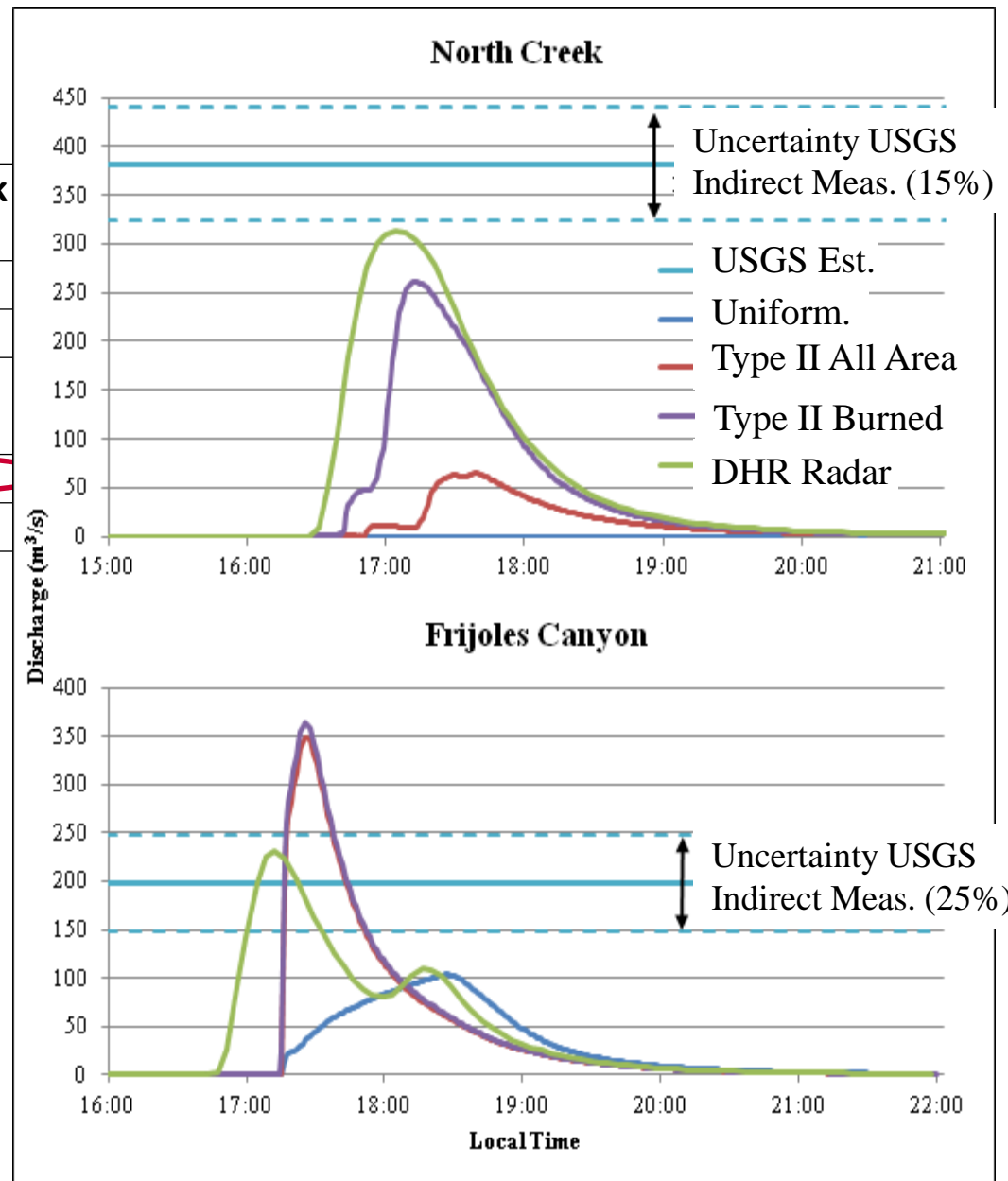
Predicting At-Risk Areas

Does rainfall representation change the model's prediction of high-risk areas?

For rapid assessment of post-fire risk, a design storm is used:
•Monsoon Storm: 2-year 30-minute, 13.18mm (0.52'')

Predicting At-Risk Areas

Which hillslopes and stream reaches have the greatest change in runoff or sediment yield from pre- to post-fire?
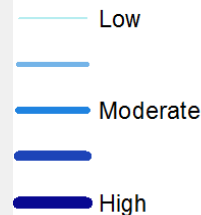
SCS Type II
over burned area

Compare peak flow and sediment yield change from 4 storms:
1. Observed Monsoon Storm
2. Uniform Intensity
3. SCS Type II over watershed
4. SCS Type II over burned area

Streams

Peak Flow (% Change)
— Low
— Moderate
— High

Hillslopes

Sediment (% Change)
Low
Moderate
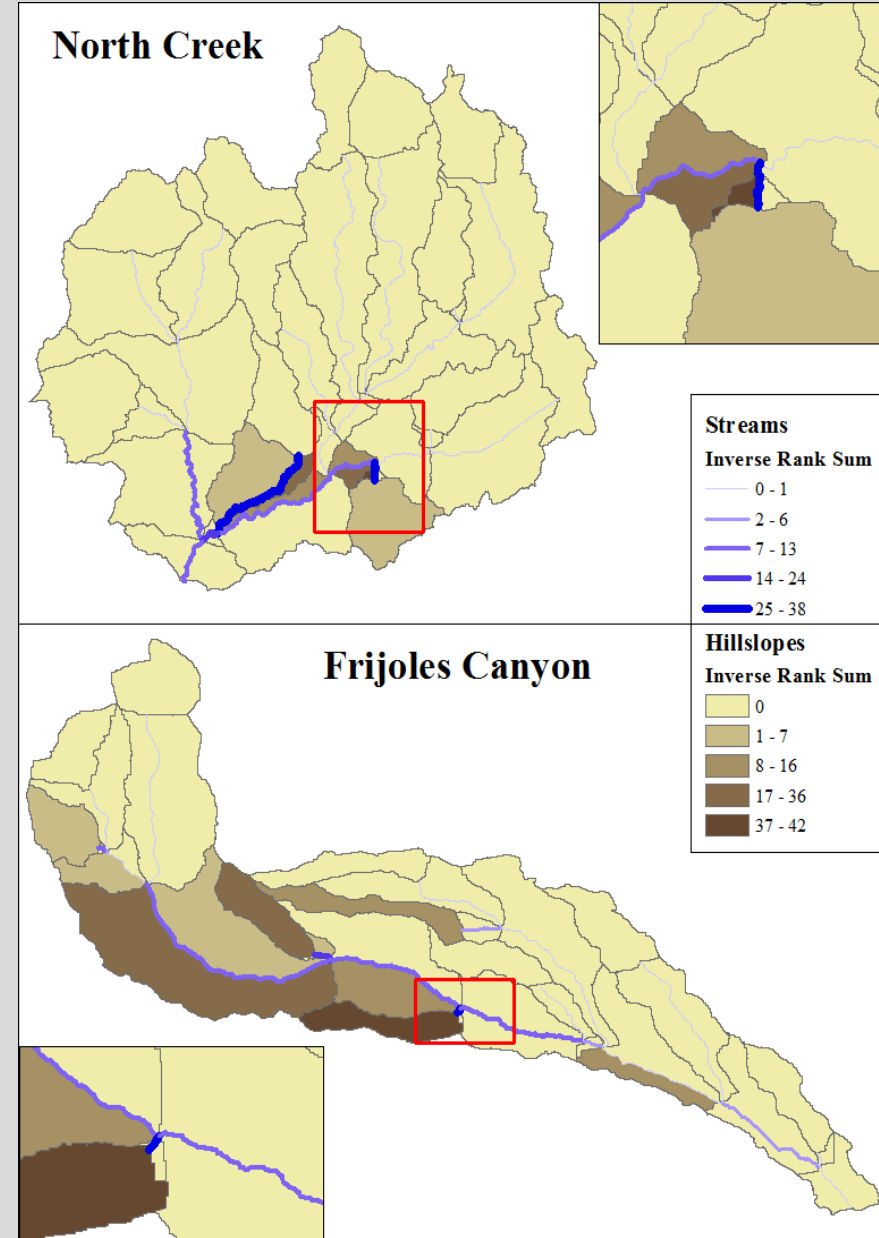High
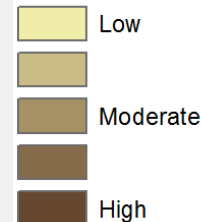
High-Risk Stream Reaches

Map of high risk areas:

To determine if rainfall representation changed the model's predicted areas of high risk, peak runoff rate of stream reaches and sediment yield of hillslopes were ranked from highest to lowest percent change from pre- to post-fire for each rainfall representation.

Comparing Ranking of Risk Areas

Statistically compare rankings with Spearman's Coefficients (SC) (SC = 1 implies perfect agreement in ranking, SC = -1 implies an inverse ranking order). *Point*: They are generally high for design storms.

North Creek (ZION)			
Peak Flow for Stream Reaches			
Type II Burned Area	0.76	0.66	0.46
0.90	**Type II Watershed**	0.84	0.73
0.89	0.98	**Uniform**	0.88
0.89	0.97	0.99	**Monsoon**
Sediment Yield for Hillslopes			
Frijoles Canyon (BAND)			
Peak Flow for Stream Reaches			
Type II Burned Area	1.00	0.83	0.83
1.00	**Type II Watershed**	0.82	0.85
0.80	0.81	**Uniform**	0.62
0.67	0.68	0.70	**Monsoon**
Sediment Yield for Hillslopes			

Rainfall-Representation Conclusions

• Rainfall representation drastically changes our ability to accurately model post-fire storm magnitude

• Radar is the best method for modeling magnitude

• High-risk areas do not vary drastically between different rainfall representations

• AGWA/KINEROS2 can reliably be used to predict relative pre- to post fire change to identify these areas

Models are more reliable at predicting relative change than absolute change

Summary

- **Changes in roughness can explain much of the post-fire hydrologic and erosion response in non-hydrophobic soils.**

- **AGWA provides framework to quickly parameterize watershed models and visualize the results.**

- **AGWA provides watershed scale assessments for both runoff and erosion / sediment transport at multiple points of potential risk and for all model elements**

Lessons Learned

- **Using a design storm with precipitation uniformly distributed over the burn area will accurately identify the ranking of pre- to post-fire percent changes in model outputs for overland and channel model elements**

- **The whole BAER Team could benefit from initial results**

- **Pre- and post-fire % difference maps can be used by BAER team to locate the threat to the downstream values at risk to optimize treatment design – save $$**

- **Helped other agencies (Army COE, State-wide Hazard Planning Groups) identify site-specific modeling needs and design of emergency warning systems**

Information

AGWA Web Pages:

http://www.tucson.ars.ag.gov/agwa/

http://www.epa.gov/nerlesd1/land-sci/agwa/

Includes:
- **Documentation**
- **Software**
- **Tutorials**
- **Pubs / Presentations**

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